A Geant4 simulation of CEvNS Glow in the DUNE Low Background Module

DUNE Low Energy Physics Group Meeting

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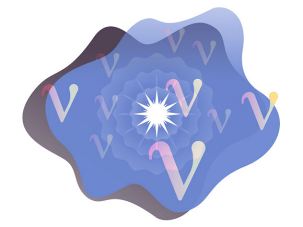
Supernova Neutrino Burts (SNBs)



In core-collapse supernovae, 99% of the gravitational binding energy is carried away in the form of neutrinos, of all flavors, in a burst that lasts roughly 10's of seconds.

- These Supernova Neutrino Bursts (SNBs) happen very rarely (a few times every century inside the Milky Way).
- It is crucial that we are able to detect as many neutrinos from a SNB as possible.

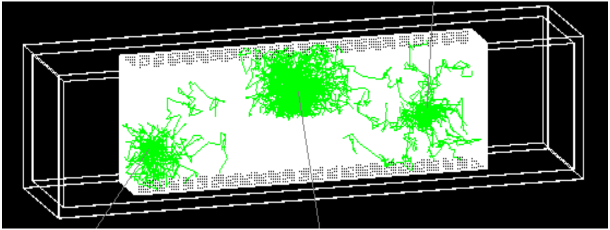
https://scitechdaily.com/images/Supernovae-are-Neutrino-Factories.jpg

CEvNS Glow

- Time-dependent structure of a SNB carries with it a lot of information useful in core-collapse physics (i.e. explosion mechanism, proto-nstar cooling, ...)
- Coherent Elastic Neutrino-Nucleus Scattering, or CEvNS, can help with elucidating this time-dependent pattern.

In large-scale scintillating detectors such as DUNE, it may be possible to observe a uniform, isotropic glow[1] of CEvNS events during a SNB, called "CEvNS Glow".

Objective

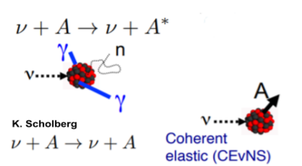


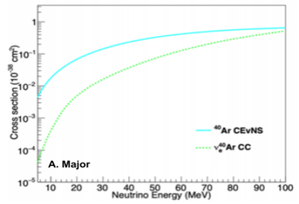
Our Goal: To investigate the CEvNS Glow of a SNB in a Geant4 sim of the Low Background Module.

- What does the signal look like/can the signal be observed given photodetection, detector properties, other interactions, background?

Coherent Elastic Neutrino-Nucleus Scattering (CEvNS)

- Neutral current interaction, flavor-blind
- Low nuclear recoil (10's of keV), large cross section

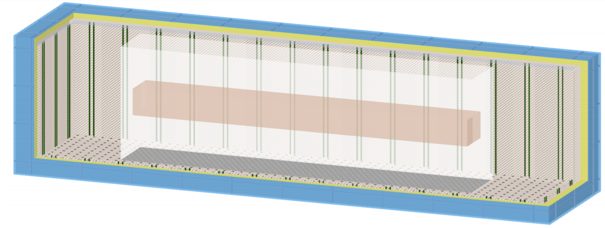




CEvNS events dominate over other interactions such as CC, but produce comparatively fewer photons per event.

- May or may not be able to reconstruct distinct CEvNS events, but we can see the time-dependent signal over the burst.
- Studying CEvNS glow is a novel way to measure neutral current signal from a SNB and observe all neutrino flavors.

Low Background Module

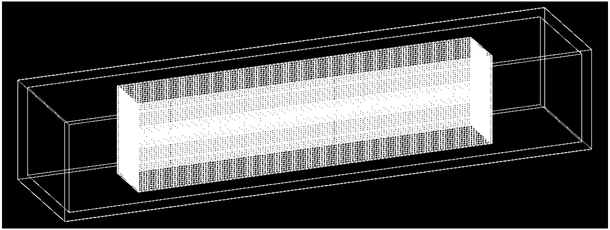


- Low-Background DUNE module, proposed in Snowmass White Paper (Back et al, 2021)[2].

Properties:

- Dual Phase (DP) Design
- Use of Argon depleted of ^{39}Ar and ^{42}Ar.
- Enhanced Photocathode Coverage
    - Lower energy thresholds, SiPMs instead of PMTs, Addition of reflectors
- Fiducial Volume surrounded by acrylic box
- Additional water shielding

DUNE-like Detector in Geant4



- Geant4 package provided by Eric Church (PNNL).
  - code can be found here: github.com/echurch/rdecay02.
- Interfaces with MARLEY for generating CC events:

$$\nu_e +^{40} \mathrm{Ar} \rightarrow \mathrm{e}^- +^{40} \mathrm{K}^*$$

Some properties:

- 2.6 kT LAr, presumed to be depleted.
- SiPMs tile the walls of the fiducial volume.
- Acrylic walls, 97% reflective, surround fiducial volume.
- G10, 44% reflective above/below.

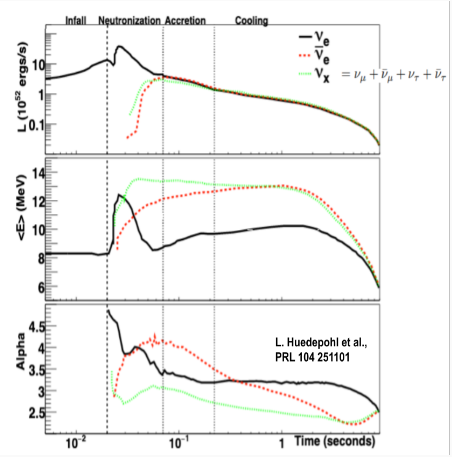
Project Details

We use the Garching parametrization to model the SNB:

$$\phi(E_\nu) = N\left(\frac{E_\nu}{\langle E_\nu \rangle}\right)^\alpha exp\left[-(\alpha+1)\frac{E_\nu}{\langle E_\nu \rangle}\right]$$

- CEvNS event rates computed using a code suite written by Dr. Scholberg.
    - github.com/schol/dukecevns
- Event rates for CC similarly provided (SNOwGLoBES).

Event rates used to sample time points at which CC/CEvNS events occur in the detector over the SNB.



Project Details

- CEvNS Recoil Energy computed from dukecevns output files.
- Event generation for CC done using MARLEY, products of interaction sent to G4 simulation.

As for Ar39 events...
We assume a reduced background as a result of using depleted argon and controls on radiopurity.

- 1/1500 decay/s/Liter of fidVol
- constant rate over the entire burst

Quantum Efficiency: 25%.

Histogram

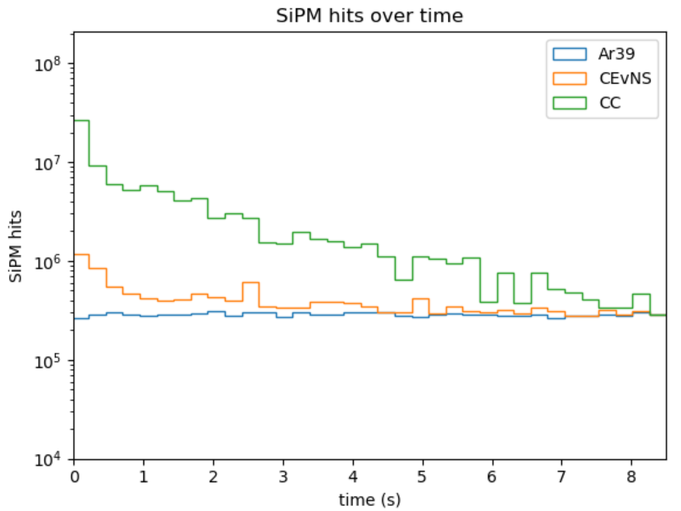


Figure 1: Histogram of no. of detector hits over time for each type of event.

Histogram

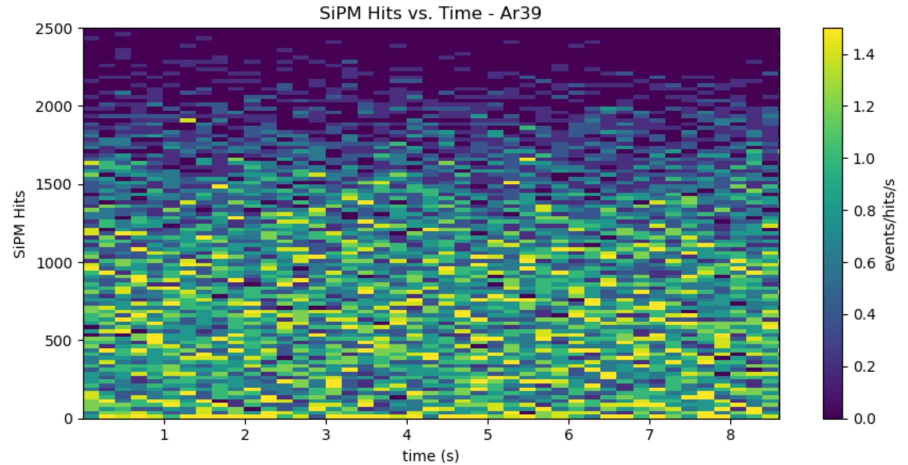


Figure 2: 2d event histogram of Ar39 beta decays. The vertical axis is the hit count of an individual event, while the horizontal axis is time.

Histogram

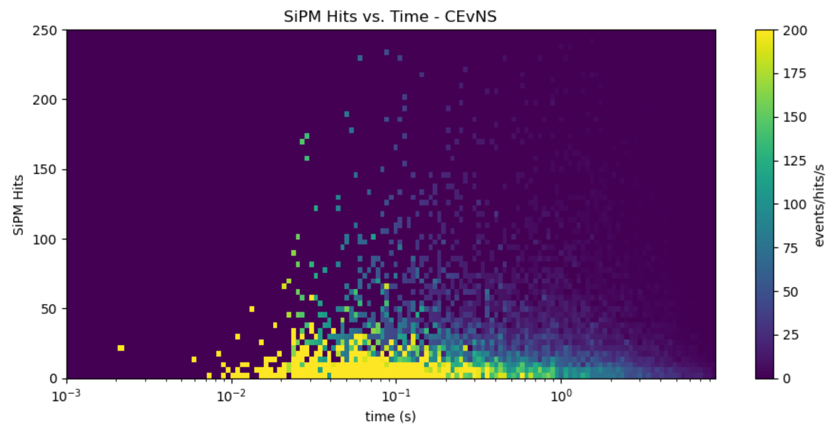


Figure 3: 2d event histogram of CEvNS events. The vertical axis is the hit count of an individual event, while the logarithmic horizontal axis is time.

Histogram

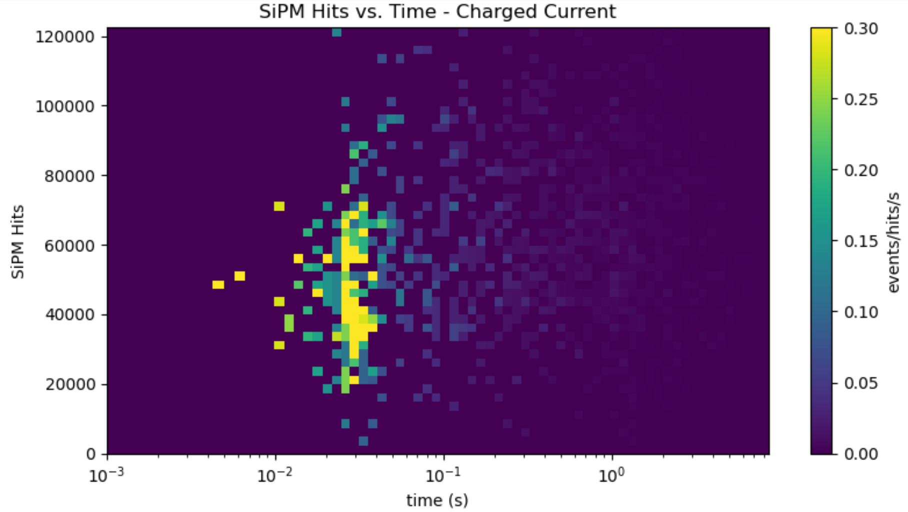


Figure 4: 2d event histogram of CC events. The vertical axis is the hit count of an individual event, while the logarithmic horizontal axis is time.

Histogram

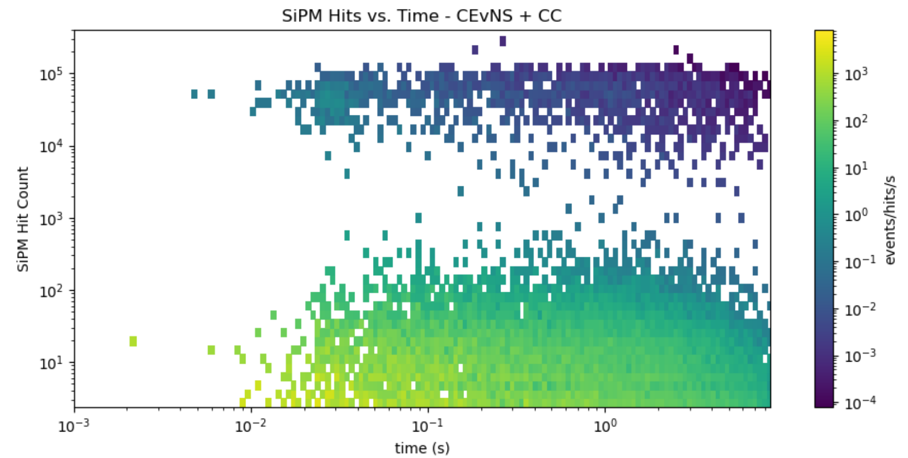
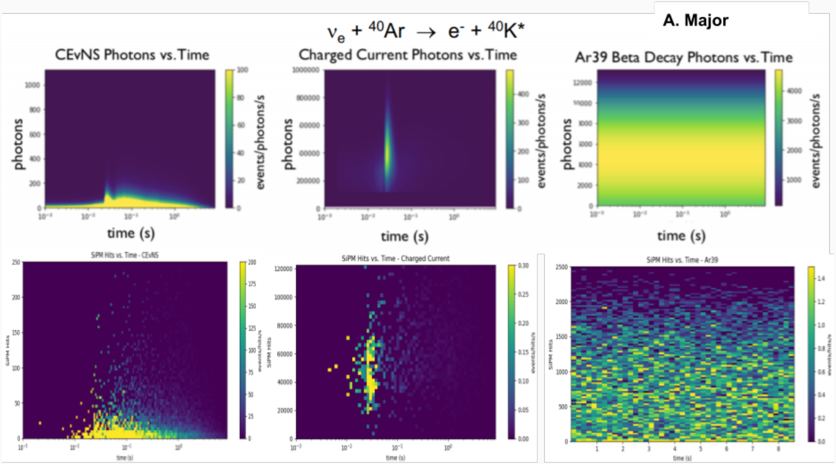


Figure 5: 2d event histogram of CEvNS and CC events. The vertical axis is the hit count of an individual event, while the horizontal axis is time.

Comparison

Comparison of results with the work of Adryanna Major:



In Closing

- CC events seen as a "spike", CEvNS events more spread out.
- Large disparity between SiPM hits for CC and CEvNS (could make them easier to distinguish), and CEvNS events occur much more often.
- CEvNS Glow signal falls off over time.
- If event reconstruction can select out the CC events, then the CEvNS Glow signal can be determined as the excess on top of the radiological background which is well-known.
- Other things such as dark rate of SiPM modules need to be considered in future studies.

Sources

[1] A. Major. (2021, February 3). *CEvNS Glow in LAr for DUNE* [Presentation]. Low Energy Physics Working Group Meeting, Fermilab. https://indico.fnal.gov/event/47584/contributions/207918/attachments/139710/175445/lepfeb32021.pdf

[2] Back, H., Beacom, J. F., Church, E., Djurcic, Z., Gil-Botella, I., Jackson, C. M., Peeters, S. J. M., Reichenbacher, J., Saldanha, R., Scholberg, K., Sinev, G., Sorel, M., Westerdale, S. (2021)., Letter of Interest - *Low Background kTon-Scale Liquid Argon Time Projection Chambers*., Snowmass 2021.